Retrieving Ionospheric Electron Density Distribution With COSMIC Occultations: An Analysis of the Effects of Geometric and Mathematical Delays on TEC Inversions From GPS/MET Occultation Data

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LONG-TERM GOALS

Because of the advantage associated with GPS/MET observations, there are many potential applications and uses of global GPS/MET observations, particularly in climate research and weather prediction. Our goal is to develop inversion algorithms for extracting bending angles and TEC inversions of the GPS signal and the distribution of ionospheric and atmospheric variables from GPS/MET occultations and to contribute our results with the scientific community for their optimum utility, especially to the ionospheric and space weather community and the meteorological community.

OBJECTIVES

The objectives of our research may be divided into two categories, short-term objectives and long-term objectives.

Our short-term objectives were to:

1. Develop retrieval algorithms for extracting the bending angle and the distribution of ionospheric (electron density) and atmospheric variables (temperature, pressure and water vapor) from GPS occultation data,

2. Infer total electron content (TEC) and precipitable water (PW) from ground-based GPS data,

3. Retrieve line-of-sight (LOS) TEC and PW from ground-based GPS data, and

4. Identify the factors that influence TEC inversion schemes.

Our long-term objectives were:

1. To develop tomography schemes for integrating the GPS occultation data and ground-based GPS data, and

2. To assimilate the tomographically derived distributions of ionospheric (electron density) and atmospheric variables (temperature, pressure and water vapor) into numerical models for advancing research in space weather and neutral weather.

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14. ABSTRACT
Because of the advantage associated with GPS/MET observations, there are many potential applications and uses of global GPS/MET observations, particularly in climate research and weather prediction. Our goal is to develop inversion algorithms for extracting bending angles and TEC inversions of the GPS signal and the distribution of ionospheric and atmospheric variables from GPS/MET occultations and to contribute our results with the scientific community for their optimum utility, especially to the ionospheric and space weather community and the meteorological community.

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APPROACH

In this report, our intention is focused on the findings about the effects of geometric and mathematical delays on TEC inversions from GPS/MET occultation data. Simulated TEC profiles were obtained from the IRI95 model. Five typical steps were performed:

1. Utilize the IRI95 model to obtain electron density profiles.

2. Calculate the bending angle of the ray path as shown in Figure 1.

3. Calculate the position, optical length, and geometric delay.

4. Calculate the TEC along the ray path.

5. Compare the retrievals of TEC with the truth (IRI95 model predictions).

I am in overall charge for the management and guidance of the proposed research. One of my graduate students, Cheng-Yung Huang, made a significant contribution in numerical modeling

WORK COMPLETED

We have completed almost the first and second steps of our short-term objectives. An inversion algorithm for extracting bending angles and the distribution of ionospheric (electron density) and atmospheric variables (temperature, pressure) from GPS/MET occultation has been developed. Retrieval results of atmospheric variables from GPS/MET occultation have been obtained and validated with the results of UCAR, NCEP and ECMWF (Liou and Huang, 2002). In addition observations of atmospheric variables (precipitable water) from ground-based GPS receivers are analyzed and validated with those from radiosonde and microwave radiometer (Liou and Huang, 2000; Liou *et al*. 2000, 2001b). The results presented in this report are satisfactory and expecting to be reported to the literature.

RESULTS

There are three major findings. First, geometric delay causes an underestimate of TEC by about 5% at NmF2. Second, the accuracy in retrieving ionospheric TEC below the E-layer is primarily dependent on the spatial resolution or the thickness of the ionospheric layer, and the other assumptions that are adopted in the retrieval algorithms. Third, the error in deriving TEC at ionospheric layers between E-layer and hmF1 is diminished to the minimum because geometric delay and errors caused by the other assumptions are cancelled out. The inhomogeneity of electron density distribution may also influence the retrieval accuracy. Inclusion of its effect as well as observations from ground-based GPS receivers shall be of interest in further improving the retrieval of TEC from the observations of space-based GPS receivers in the future.

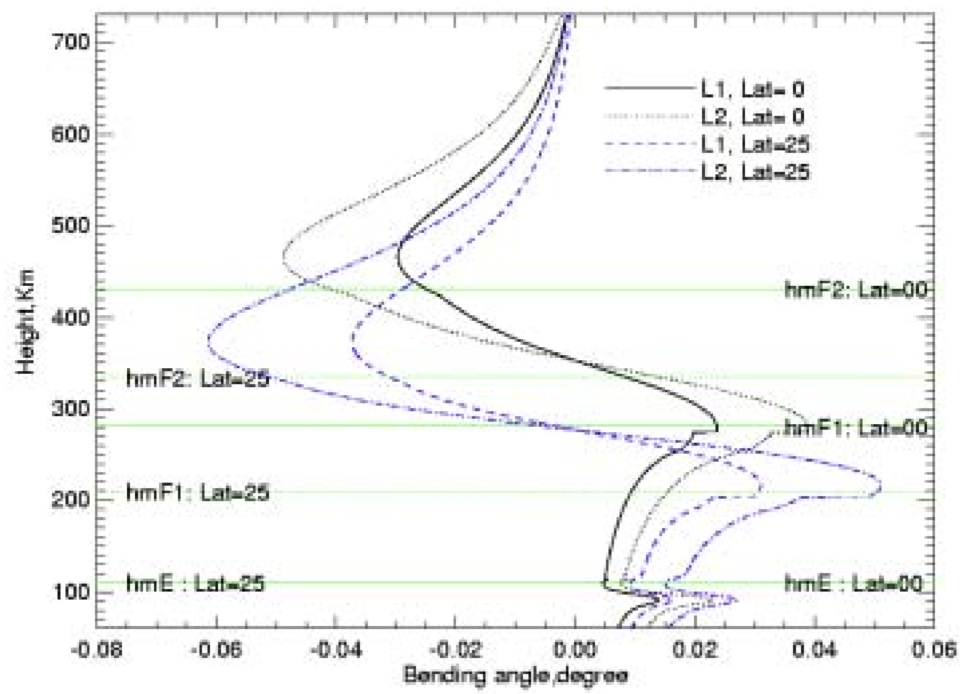

Figure 1. Bending angle. [Bending angles induced by the ionosphere at 2 latitudes, 0 and 25 degrees. Positive bending is defined to be toward the earth's center. Horizontal lines represent the typical heights of the associate layers, hmE, hmF1, and hmF2.]

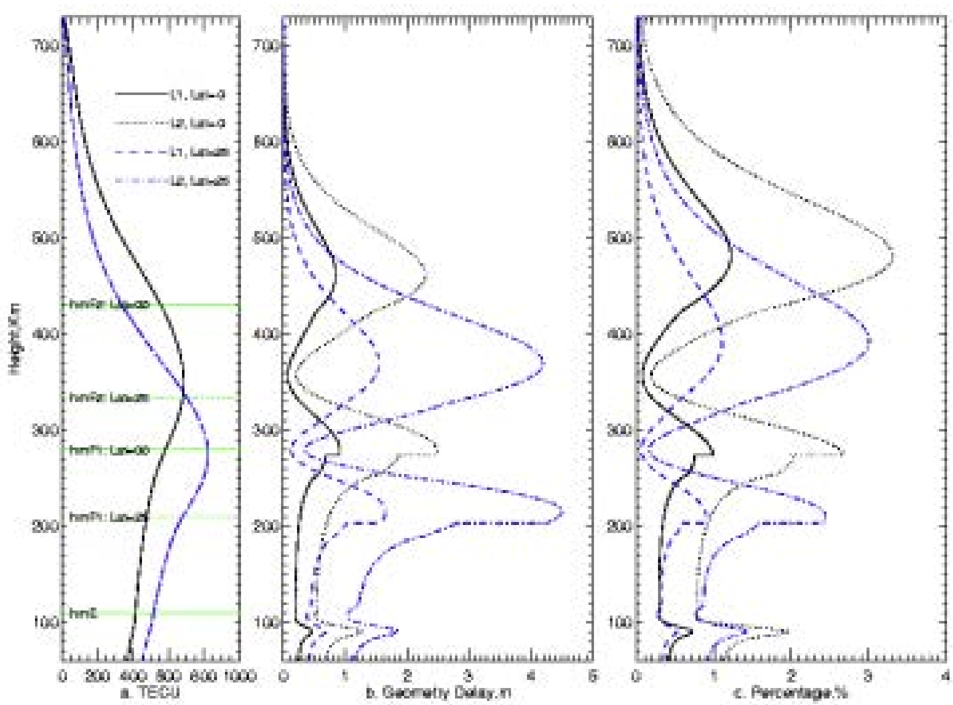

Figure 2. TECU and Geometric delay. [(a) TEC profile. (b) The geometric delay. (c) The ratio between geometric delay and TEC delay (in percentage).]

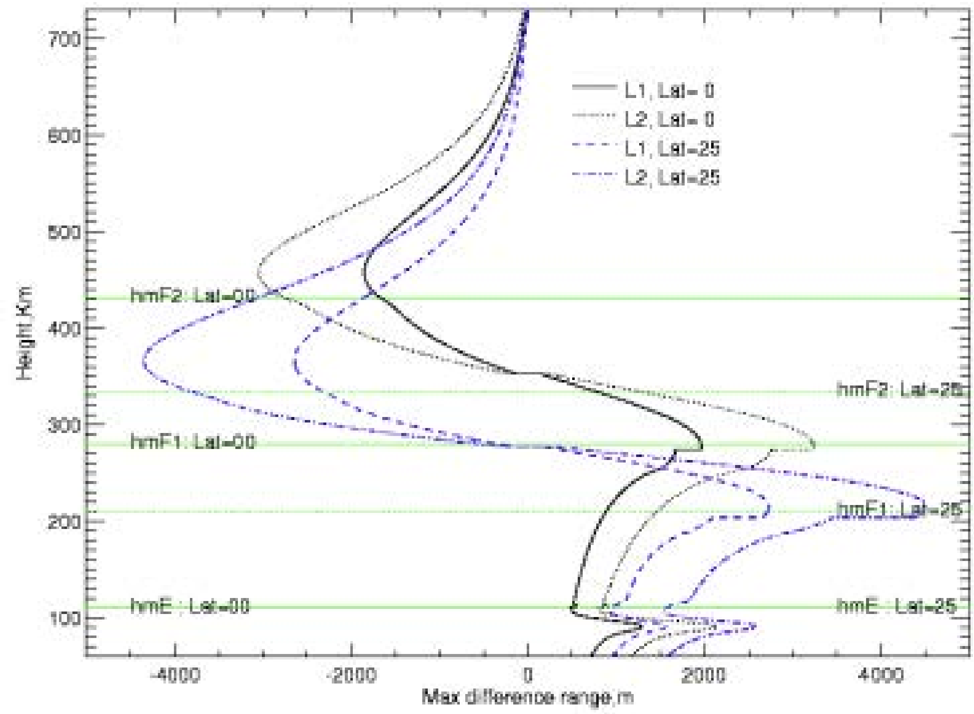

Figure 3. Maximum differential range. [The maximum difference in distance between the simulated ray path and the straight line from LEO to GPS satellites.]

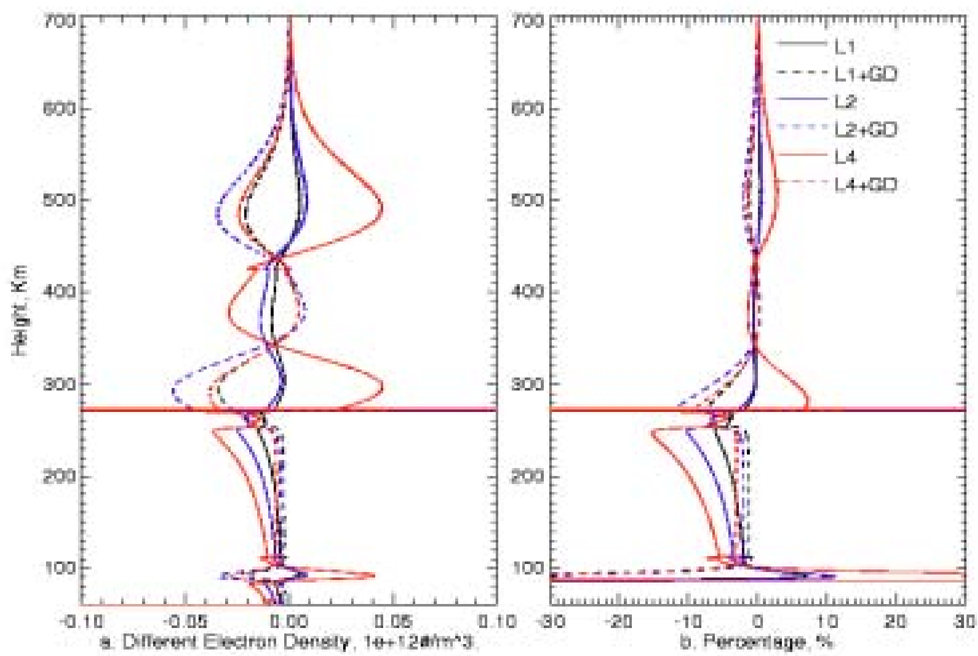

Figure 4. Differential electron density with geometric delay. [(a) Difference in electron density between simulation and truth (the IRI95 model predictions) (Differential Electron Density; DED). (b) The ratio between DED and truth for the case of latitude 0 degree. The errors are enlarged if geometric delay (GD) is not corrected.]

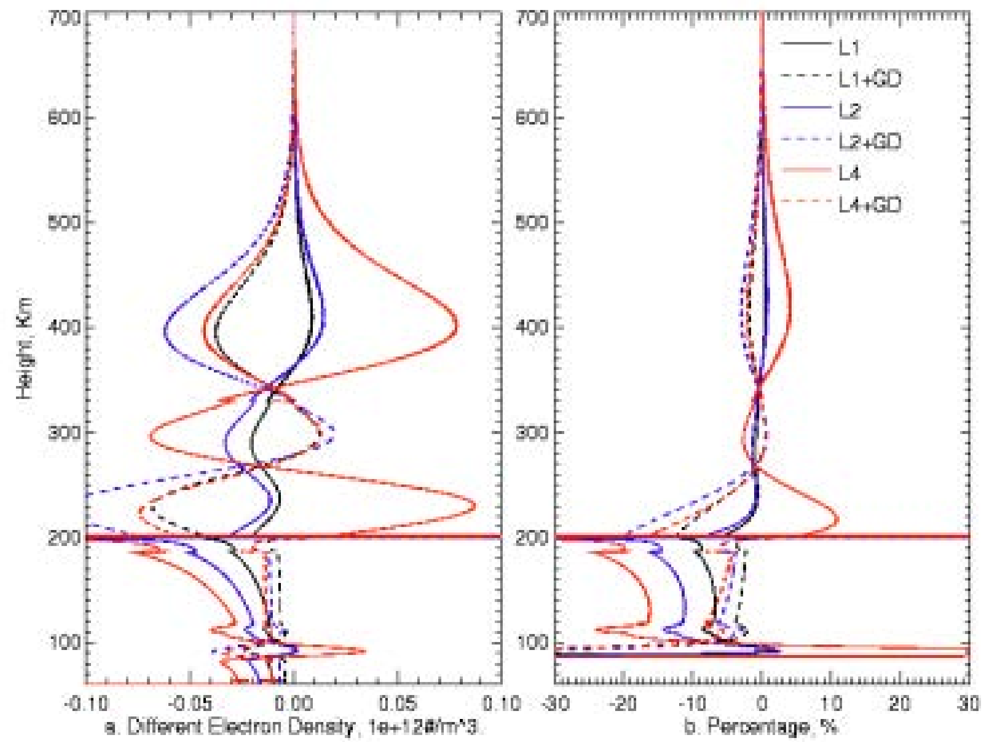

Figure 5. Different electron density without geometric delay. [(a) Difference in electron density between simulation and truth (the IRI95 model predictions). (b) The ratio between DED and truth for case of latitude 25 degree. The errors are enlarged if geometric delay (GD) is not corrected.]

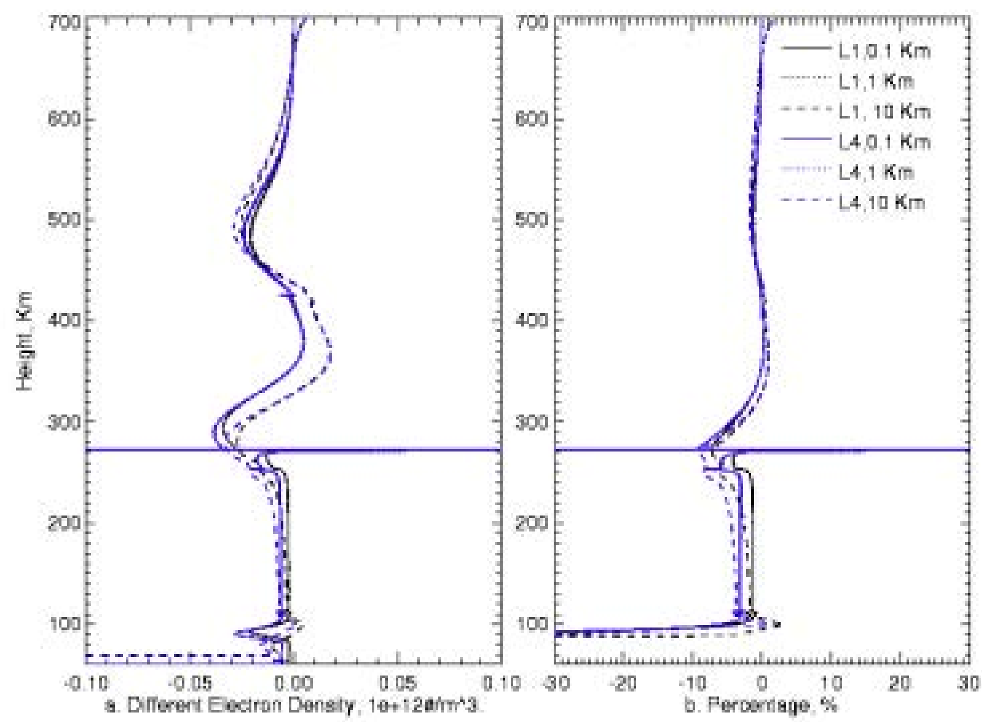

Figure 6. Differential electron density. [Spatial resolution's influence on the TEC retrieval with geometric delay. The errors are decreased with increasing spatial resolution.]

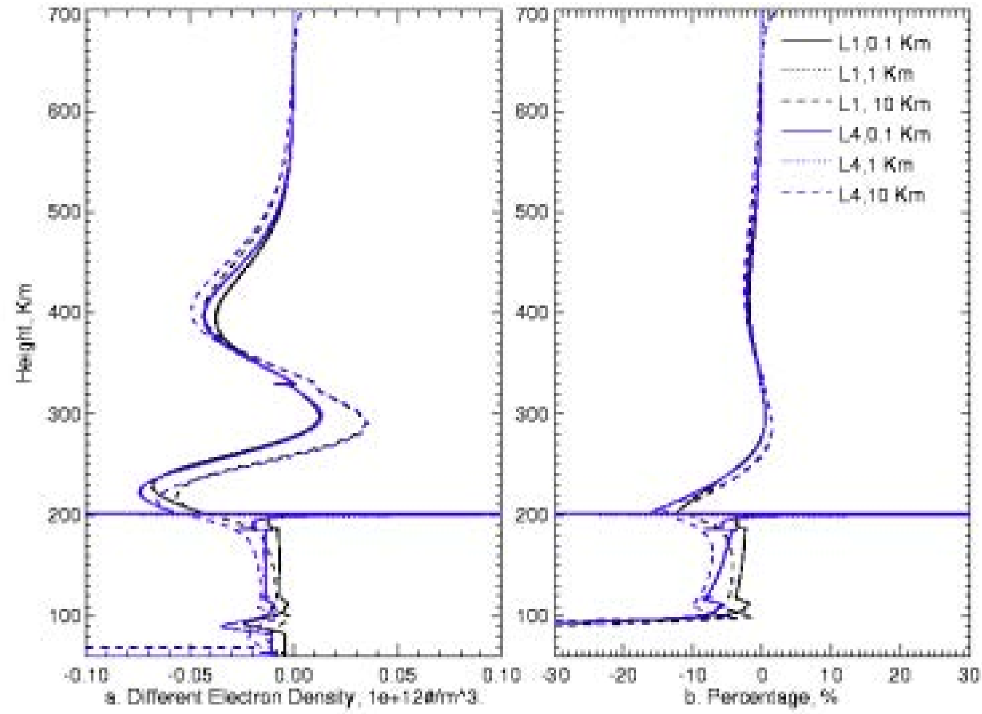

Figure 7. Differential electron density. [Spatial resolution's influence on the TEC retrieval without geometric delay.]

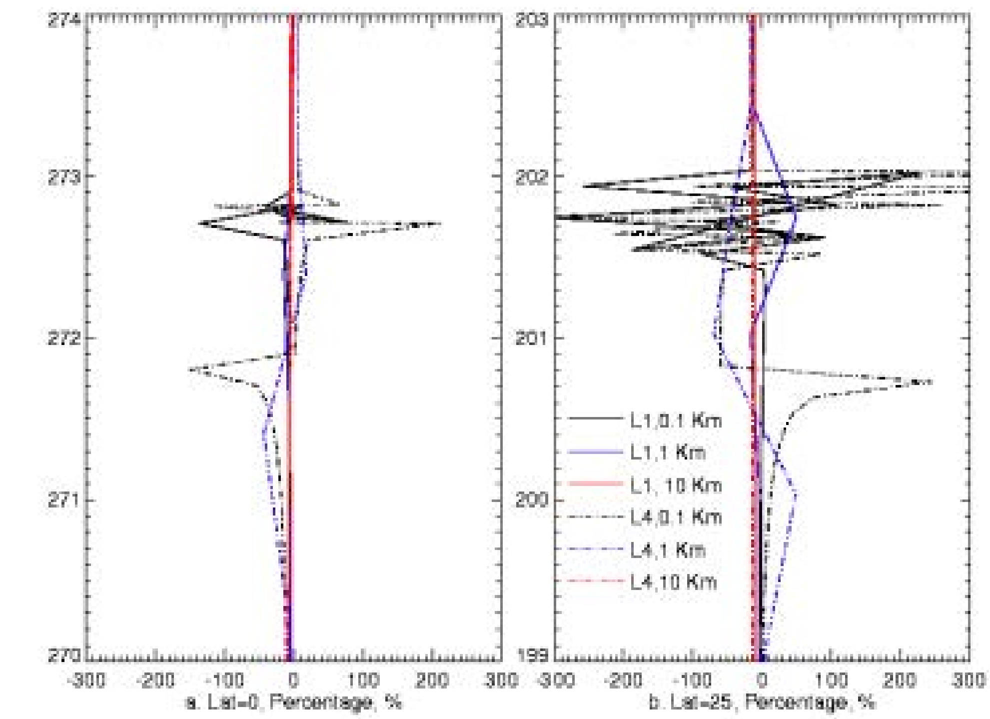

Figure 8. Differential electron density at regions where the errors are large. [Spatial resolution's influence on the TEC retrieval. The solution is sensitive to the spatial resolution. However, the errors may be enlarged at the regions where electron density varies quickly for the high-resolution case.]

IMPACT/APPLICATION

To our knowledge, it is a common problem to underestimate TEC at NmF2 by the GPS/MET occultation technique in the literature. In this study, it is found that the underestimate is primarily caused by the computation of geometric delay in the retrieval algorithm. This suggests that geometric delay must be taken into account in the retrieval algorithms. With this finding, we will further investigate the other factors that might have caused the retrieval errors in the GPS/MET occultation technique.

TRANSITIONS

Products of occulted TEC from our inversion algorithms would be used by NRL to determine 2-dimensional structure of the ionosphere with TIP measurements.

RELATED PROJECTS

I am also a Principal Investigator of the project "Retrieval and validation of neutral atmospheric parameters from ROCSAT-III" under grant NSC90-2111-M-008-047-AGC (90/08~92/07) sponsored by National Science Council, Republic of China.

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